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NAVIGATION IMPROVEMENT STUDY OF THE UPPER MISSISSIPPI RIVER NEAR SAVANNA BAY, POOL 13

SEDIMENTATION AND HYDRODYNAMIC INVESTIGATION

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14. ABSTRACT
A navigation improvement study near Savanna Bay, pool 13 of the Upper Mississippi River, was conducted by the Rock Island District, Army Corps of Engineers. The study was carried out in order to evaluate a number of design alternative impacts for channel improvement between Mississippi River Miles 540 to 538. The effort focussed on studying the effects of various structural measures on both the navigation channel and an adjacent side channel. The goal was to alleviate or minimize historical maintenance dredging in the navigation channel while ensuring no negative environmental impacts within the side channel.
The physical hydraulic Micro Model methodology and the numerical SMS model were used as applied river engineering tools to evaluate measures for channel improvement and environmental impacts. The tools examined the general expected flow and sediment response that could be expected to occur in the river as a result of a variety of design alternatives These alternatives were formulated by a team of interagency members including the Rock Island and St. Louis District Army Corps of Engineers, the Illinois Department of Natural Resources, and the U.S. Fish and Wildlife Service.

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INTRODUCTION

A navigation improvement study near Savanna Bay, pool 13 of the Upper Mississippi River, was initiated by the Channel Maintenance Section, Operations Branch, of the Rock Island District. The study was carried out in order to evaluate a number of design alternatives and/or modifications for channel improvement between River Miles 540 and 538.

Personnel from the Rock Island District directly in charge of the study and overseeing the project include; Mr. Alois J. Devos, Chief, Channel Maintenance Section, Mr. Michael D. Cox, Channel Maintenance Coordinator, Mr. Kenneth J. Brenner and Mr. Richard E. Vale, Dredging Coordinators, Mr. James A. Adaila, GIS Engineer, and Ms. Erika Mark, biologist for the Environmental Branch.

The study was conducted during the period July 1997 to November 1997 using a physical micro model and a numerical model. The micro model was setup at the St. Louis District Applied River Engineering Center, St. Louis, MO. Personnel operating the micro model included Mr. Chad Mathes, Mr. David Gordon and Mr. Robert Hetrick, hydraulic engineers, under the direct supervision of Mr. Robert Davinroy, potamologist for the St. Louis District.

All numerical modeling was conducted within the Rock Island District by Mr. Thomas A Kirkeeng, hydraulic engineer, under direct supervision of Mr. Marvin R. Martens, Chief, Hydrologic Engineering Section.

Personnel from other agencies also involved in the study included: Mr. Dan Sallee, Illinois Department of Natural Resources, and Mr. Robert Clevenstine, U.S. Fish and Wildlife Service.

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BACKGROUND

This report details the investigation of a navigation improvement study of the Upper Mississippi River near Savanna Bay, Miles 540 to 538. Micro Modeling methodology, flow visualization, and SMS modeling were used to evaluate the sediment transport and hydrodynamic response trends that could be expected to occur in the river from various applied channel improvement measures.

Design alternatives were conceptualized and submitted by members of a study team representing the U.S. Army Corps of Engineers, Rock Island and St. Louis Districts, the Illinois Department of Natural Resources, and the U.S. Fish and Wildlife Service. The primary goal was to evaluate the positive impacts of these alternatives, if any, on the resultant bed configuration (sediment transport response) and hydrodynamic response (flow patterns and velocity vectors) within the Upper Mississippi River, Savanna Bay study reach. Designing for a reliable navigation channel, while at the same time ensuring that no negative environmental impacts occur in an adjacent side channel, was the major goal of this study.

1. Problem Description

Plate 1 is a map depicting the characteristics, configuration, and nomenclature of the Upper Mississippi River through this particular study reach. The Rock Island District has performed a substantial amount of historical and modern day maintenance dredging in this reach of river to ensure a reliable navigation channel. Plate 2 contains a map depicting historical dredge cuts and disposal areas performed by the Rock Island District between 1958 and 1995.

The dredging problem is due primarily to the general planform configuration (Plate 3) and boundary effects of the river. The river loses its ability to maintain

adequate navigation depths between River Miles 540 and 538. Effectively, the channel thalweg lies on the outside of a sharp radius bend through this area. A depositional point bar predominates on the inside of the bend. Also, a certain amount of energy is lost within the adjacent side channel. Finally, the physical location of existing islands (Plate 3, Santa Fe Beach, Island 266, and Sweeney Islands) and the respective revetments generate localized scour effects that also may contribute to localized deposition within the navigation channel.

The adjacent side channel complex contains important fisheries attributes (Deelan, Clevenstine 1997). Sufficient depths in the lower one third of the side channel serve as over-wintering areas for a variety of fish species.

In 1997, Rock Island and St. Louis District engineers made a field inspection of the study reach. Plates 4 through 10 are descriptive photographs taken during this inspection illustrating various segments of the study reach. The following observations were noted:

- There was an apparent amount of non-erodable material near the entrance to Savanna Bay, possibly in the form of consolidated clay, as evidenced by the lack of lateral erosion on the left descending bank of the upper one third of the side channel.

- The greatest area of energy (turbulence, velocities, and depths) within mile 540 to 538 seemed to occur within the opening between Island 266 and upper Sweeney Island (Plates 8 and 9).

- The opening between Sweeney Islands was larger than anticipated (Plate 10). During model tests, it was observed that this opening was a sensitive, critical area of the side channel. Any changes made to the upstream flow

and sediment response of the river dramatically changed conditions through this opening, as discussed later in this report.

2. Study Purpose and Goals

The study was performed to address the effects of various design alternatives or measures to alleviate or eliminate the maintenance dredging between Miles 540 and 538. The goal was to ensure that any positive measures upon the navigation channel realized from a particular alternative would not adversely change the bed conditions within the side channel.

MICRO MODEL DESCRIPTION

1. Scales and Bed Materials

Plate 11 is a photograph of the Savanna Bay hydraulic micro model used in this study. The scales were 1inch = 400 feet, or 1:4800 horizontal, 1 inch =50 feet, or 1:600 vertically, for an 8:1 distortion ratio. This distortion supplied the necessary forces required for the simulation of sediment transport conditions similar to the prototype. The bed material was granular plastic urea, Type II, with a specific gravity of 1.23.

2. Apperturences

The model was constructed according to 1996 aerial photographs of the Upper Mississippi River. Flow was controlled via an electronic/computer interface and mechanical control valve. Stages and resultant bed configurations were surveyed with a 3-dimensional digitizer and computer interface. Slope was controlled by rotational jacks located within the hydraulic flume.

MICRO MODEL TESTS

1. Calibration and Verification

The calibration/verification of the micro model involved the adjustment of water discharge, sediment load, time scale, and slope. These parameters were adjusted until the measured bed response of the model was similar to the prototype (1).

A. Design Hydrograph

The effective discharge (2) run throughout his model represented that hydrograph where normal sediment transport would be expected to occur in the prototype. In this particular study, a steady-state effective discharge was simulated to represent the average expected sediment response during open-river conditions. Because of the constant variation experienced in the prototype, the effective discharge was used to theoretically analyze the average expected sediment response during any given year.

B. Historical and Modern Day Prototype Surveys

Several historical and modern day prototype surveys were used to determine the general bed characteristics that have existed in the prototype over the years (Plates 12 through 20). In the late 1880's (Plate 12), the survey shows that the thalweg of the main channel was well away from the left descending bank between Miles 540 and 538. From 1927 to the present (Plates 13 through 20), surveys show that the thalweg through this same area clearly shifted toward the left descending bank. The bathymetry during this time period also indicates that the relative depths and distribution of the bed have remained fairly consistent. The general trend since 1927 has been the occurrence of a dominant point bar

located off the right descending bank and the development of a marginal navigation channel adjacent to this bar. The thalweg has primarily remained directly against the islands off the left descending bank.

2. Base Test

A. Base Test Survey

Plate 21 shows the resultant bed configuration of the micro model base test. The model was broken up into four classification reaches during calibration (Plate 22); the entrance reach, the transition reach, the calibrated reach, and the exit reach. The reach limits were labeled and compared to the prototype. The calibration reach survey (Plate 23) served as the comparison survey for all future design alternative tests. The base test was developed from the simulation of successive design hydrographs until bed stability was reached and a similar bed response was achieved as compared with the prototype surveys. Results of the base test and comparison to the prototype indicated the following trends:

The micro model was calibrated using the 1996 Mississippi River survey of Miles 542 to 537 and historical dredge surveys from 1958 through 1995. The 1996 survey (Plate 19) overall depicted a pronounced decrease in the depth of the navigation channel on the riverside of Island 266. This area near "Savanna Bay" has been repeatedly dredged in the past and was of primary concern in this study, as evidenced by the historical dredging scenarios of the Rock Island District (Plate 2).

The entrance flow point of the micro model began at Mile 542. The actual study reach by which the model tests were conducted was between Miles 540 and 538 (calibration reach, Plate 22). The model entrance conditions were adjusted until

general bed trends were established above the 2-mile study reach, between Miles 542 and 540.

In the prototype surveys, between Mile 541.4 and 540.9, right descending bank, there has been the occurrence of a predominant scour hole adjacent to the existing rock bluff at Lainsville, Iowa. Surveys have indicated that depths have approached 40 feet below design pool in this area. Conditions at the upstream entrance point of the model were adjusted until a satisfactory bed response was achieved in this area of scour.

Between Miles 540.8 and 540.7, the channel in the model was not well defined as compared to the prototype. This was attributed in part to the proximity of the nearby entrance conditions and the upstream scour off the right descending bank. This depositional tendency was repeatable throughout all model tests.

At the center of Riprap Island, Mile 540.6, prototype surveys revealed the occurrence of a deep scour hole off the revetted tip at the north side of the island. This scour hole trend was evident in the model and repeatable during all tests.

Downstream of RipRap Island, at Mile 540.3, the prototype displayed channel depths of -30 feet off the right descending bank. In the model, depths throughout this area were generally shallower (-10 to -20 feet).

At the start of the study reach, between Mile 540 and 539, both the prototype and the model displayed a similar channel crossing, although the model channel was slightly shallower.

At the critical dredging area, between Mile 539 and Mile 538.5, historical and recent prototype surveys revealed a predominant point bar development off the

right descending bank. The bar has extended toward Island 266 and Sweeney Islands. The tendency for shoaling through this area and the general bed configuration of the point bar was replicated in the model.

On the left descending side of Island 266 and Sweeney Islands within the upper two thirds of the side channel, depths in the prototype were surprisingly small (-10 to -20 feet). Bed sediment samples conducted by Rock Island District in 1997 indicated that a fair amount of clay/sand mixture existed throughout this area, supplying an indicator of low erosion and sediment transport potential. During initial calibration, the model displayed a tendency for a large amount of scour through this area. Most of the energy was concentrated at the apex of the bend of the side channel directly behind Island 266. To compensate for this overabundance of scour, the model bed was molded out of clay throughout this area. Once this portion of the model bed was fixed, the sediment response in the main navigation channel behaved properly downstream of the islands off the left descending bluff bank between River Miles 538.6 to 538.

Depths near the upper end of the Island 266 revetment was exaggerated in the model. This was attributed to a combination of factors, including model distortion (the model scale was distorted 8 times to achieve favorable sediment transport), possible non-erodable material contained in the prototype as compared to the model, and an exaggeration of localized turbulence in the model as compared to the prototype. These exaggerated depths were repeatable in the model throughout the calibration process, base test, and design alternative tests.

In the navigation channel at Mile 538.7, the model had a tendency to shoal in this area (-8 to -10 feet), while the channel in the prototype surveys remained fairly deep (-10 to -20 feet).

At Mile 538, the channel was deep (-30 feet) and developed just off the left descending bluff at Mississippi Palisades State Park in both the model and the prototype.

B. Base Test Flow Visualization

In addition to the bathymetry collected from the model, flow visualization information was also collected. Photographic time exposure was used to examine the general surface velocity patterns of each model test. The visualization photo prints were placed on the plates of the model bathymetry maps to represent general flow conditions experienced during each model test.

The base test visualization photography was further analyzed and output as a vectorized plan view map (Plate 24). The map was developed using a methodology similar in nature to a fully automated computerized process known as particle image velocimetry. Because the exposure of the film was known, measuring the length of the confetti streaks yielded a unitless velocity coefficient. Since all of the floating particles in the frame were exposed to the film for the same length of time, the dimensioned photograph could be interpreted as a type of normalized velocity diagram.

Analysis of both the time exposure image and vectorized map for the base test condition indicated that the highest velocities were contained in the main channel. Also, relatively high velocities were encountered (2.2) between Island 266 and Sweeney Islands. This area of high energy was verified in the field and also later depicted in the SMS modeling effort (Plates 39, 40, and 41).

3. Design Alternative Tests

A number of alternative design plans were tested in this study. The effectiveness of each plan was evaluated by comparing results to the base test.

Alternative 1. *Closure Structures Behind Island 266 and Between Island 266 and Upper Sweeney Island.* Alternative 1 involved the placement of two closure structures (height of 2 feet below Flat Pool), one closure placed behind or to the outside of Island 266, and the other structure placed between Island 266 and upper Sweeney Island. In this particular configuration, the upstream closure structure was placed approximately 500 feet behind the nose of Island 266. Model bathymetry and flow visualization (Plate 25) defined the following trends:

Depths increased at the upper end of Island 266, which widened and deepened the navigation channel downstream. However, the redistribution of flow through the main channel caused changes in the sediment transport characteristics downstream of Sweeney Islands, from approximately Mile 538.7 to the end of the study reach. A middle bar developed in this area.

Within the side channel, several changes occurred. Immediately downstream of the first upstream closure, a minimal amount of deposition was observed in the model. The middle one third of the side channel remained free of deposition, while the lower one third of the side channel experienced 10 to 20 feet of additional deposition. The source of this sediment came from the opening between the two Sweeney Islands (Mile 538.7). The changes in sediment transport experienced in both the main channel and the side channel caused sediment to enter through this opening and form a depositional delta in the side channel in both the upstream and downstream direction.

Alternative 2. Closure Structures at the Nose of Island 266 and Between Island 266 and Sweeney Islands. Alternative 2 involved the placement of two closure structures (height of 2 feet below Flat Pool); the most upstream closure was placed just to the outside of Island 266 and closer to the navigation channel as compared to Alternative 1. The second closure remained in the same configuration as in Alternative 1. Model bathymetry and flow visualization (Plate 26) defined the following trends:

Depths again increased at the upper end of Island 266, but the flow was more streamlined in the navigation channel. The result was an extremely favorable improvement to the navigation channel (a widening and deepening of the channel), especially from Mile 538.9 to Mile 538.6.

Downstream of Mile 538.6, there was a decrease in the depth of the navigation channel as compared to the base test (approximately 10 feet against the left descending bank at Mississippi Palisades State Park).

In the side channel, there was a slight tendency for deposition in the upper one third of the channel (0 to 2 feet). The middle one third of the channel remained essentially the same. The lower one third again experienced delta deposition entering from the lower opening at Sweeney Islands. This trend was again similar to the results of Alternative 1 testing.

Alternative 3. *Two Perpendicular Wing Dams in Combination with Alternative 1 Closure Structures.* Alternative 3 involved the placement of two perpendicular wing dams located off the left descending bank at Mile 539.6 in addition to the closure structures of Alternative 1. Model bathymetry and flow visualization (Plate 27) defined the following trends:

The wing dam/closure structure configuration generated a substantial improvement to the navigation channel in the dredging area. However, the redirection of flowlines caused more energy to be diverted directly toward Sweeney Island, resulting in a pronounced increase in scour off this particular revetment. The changed flow condition at Sweeney Islands caused energy to be directed downstream toward the right descending bank at Boy Scout Island. A small shoaling area occurred in the middle of the navigation channel at Mile 538.3.

In the side channel, depths remained essentially the same, except for the lower one third reach, which again experienced delta deposition from sediment entering the most downstream island opening.

<u>Alternative 4.</u> ***<u>Two Perpendicular Wing Dams in Combination with Alternative 2 Closure Structures.</u>*** Alternative 4 involved the placement of two perpendicular wing dams, length of 500 feet, height of 5 feet below Flat Pool, located off the left descending bank at Mile 539.6, in addition to the closure structures of Alternative 2. Model bathymetry and flow visualization (Plate 28) defined the following trends:

The wing dams improved the navigation channel throughout the bend. However, as with the previous alternative, the redirection of flows through the bend caused unfavorable conditions to occur downstream . The thalweg developed again off the right descending bank at Boy Scout Island. The flow and sediment transport scheme in this area basically reversed as compared to base test conditions.

The side channel was again primarily effected by delta sediment coming for the most downstream opening into the lower one third of the channel. The rest of the side channel remained essentially sediment free.

Alternative 5. ***Two Perpendicular Wing Dams with No Closures.*** Alternative 5 involved the placement of two perpendicular wing dams as in previous tests with no closure structures. Model bathymetry and flow visualization (Plate 29) defined the following trends:

The wing dams without the closure structures made improvements to the navigation channel. The flow was again directed away from the upper end of Island 266 and moved toward the Sweeney Islands revetment. Just downstream of Sweeney Islands, the channel depth increased approximately 10 feet as compared with the best test (where the channel was originally lost at Mile 538.7). Downstream of this area, the navigation channel remained primarily the same. A tendency for some deepening was still noted at Boy Scout Island. In the side channel, conditions remained the same as observed in the base test.

Alternative 6. ***Connection of the Revetments of Island 266 and Upper Sweeney Island.*** Alternative 6 involved the connection of revetments of Island 266 and upper Sweeney Island. Model bathymetry and flow visualization (Plate 30) defined the following trends:

Overall depths near the upper end of Island 266 were greatly reduced by this alternative. The navigation channel slightly narrowed in width as compared to the base test. Some additional channel depth was gained adjacent to Sweeney Islands at Mile 538.7. In the side channel, conditions remained the same as observed in the base test.

Alternative 7. ***Wing Dam at Island 266 Revetment.*** Alternative 7 involved placing a small perpendicular wing dam (400 feet in length and height of 5 feet below Flat Pool) out into the navigation channel off the revetment of Island 266. Model bathymetry and flow visualization (Plate 31) defined the following trends:

The structure reduced general depths around Island 266, but did not improve the navigation channel. Deposition occurred in the channel at Mile 538.7. In the side channel, the conditions remained the same as observed in the base test.

Alternative 8. *Three Bar Wing Dams Off the Right Descending Bank.* Alternative 8 involved the placement of three bar wing dams (height of 5 feet below Flat Pool) off the right descending bank approximately opposite the apex of the bend. The effective lengths of the wing dams followed the general width of the existing point bar. Model bathymetry and flow visualization (Plate 32) defined the following trends:

The wing dams on the bar did not effectively improve the navigation channel, especially adjacent from Island 266. Other wing dams on the bar were visually tested in the model and observed for any positive effects to the channel. No combination of wing dams on the bar positively effected the navigation channel to justify further testing of structures on the bar.

Alternative 9. *Three Closure Structures Between Island 266 and Sweeney Islands.* This alternative involved the closure structure configuration of alternative two with the addition of a small closure structure (height of 2 feet below Flat Pool) at the most downstream opening between Sweeney Islands. Model bathymetry and flow visualization (Plate 33) defined the following trends:

The third closure structure eliminated the tendency for delta deposition to occur within the lower third of the side channel. Results indicated additional channel width and depth was gained through the dredging area (between Mile 539.2 to 538.6). Downstream, the channel decreased in depth significantly along the bluff at Mississippi Palisades State Park as compared to the base test. A tendency for deepening was also observed at Boy Scout Island.

Alternative 10. *Second Closure Structure Moved Toward the Main Channel.* This closure structure configuration was similar to the configuration of alternative nine, with the exception of the position of the second closure structure between Island 266 and Sweeney Island. The structure was moved toward the river approximately 200 feet. Model bathymetry and flow visualization (Plate 34) defined the following trends:

The navigation channel widened and deepened through the dredging area with the exception of a small, isolated depositional area within the middle of the channel at 538.8. Downstream, the channel had a tendency to shallow against the left descending bank at Mississippi Palisades State Park. The side channel remained free of additional deposition.

Alternative 11. *Closure Structures Lowered.* This closure structure configuration was similar to that of alternative nine, but the closure structures were placed at a lower elevation (5 feet below Flat Pool). Model bathymetry and flow visualization (Plate 35) defined the following trends:

The navigation channel widened and deepened through the dredging area. Localized scour near the revetments were reduced as a result of lowering the closure structures. Downstream, the channel had a tendency to shallow against the left descending bank at Mississippi Palisades State Park, although not to the degree of the closure structure test of alternative 9. The side channel remained free of additional deposition.

NUMERICAL MODEL

1. Description

The numerical model used for the flow analysis in this study was the Surface Water Modeling System (SMS). SMS is a pre-and post-processor for building grids, viewing solutions, and many other specialized tasks. Plate 36 is a plan view map of the finite element grid developed for this study. SMS is the interface for the TABS suite of surface water numerical modeling programs. The TABS numerical modeling system is a collection of computer programs designed for studying multi-dimensional hydrodynamics in rivers, reservoirs, bays, and estuaries. This modeling system can be used to predict the magnitude and direction of depth averaged velocities. The TABS modeling system has been applied to calculate flow distribution around islands, flows in contracting and expanding reaches, flows at river junctions, and general flow patterns in rivers, reservoirs, and estuaries. Project impacts on flows, sedimentation, constituent transport, and salinity can be predicted (4).

2. Calibration

The SMS model was calibrated using two methods. First, the water surface elevation on the downstream end of the model and the flow on the upstream end were input as boundary conditions. These values were acquired from published water surface profiles. The model was then calibrated to the upstream water surface elevation by adjusting model roughness (Manning's n-values).

The next calibration step involved the adjustment of turbulent exchange coefficients. Prototype flow measurements were available. The flow and water surface elevation at the time of measurements were input into the model. The

model was then calibrated to the flow division between the main channel and the side channel by adjusting the turbulent exchange coefficients.

Flow measurements were taken on 29 October 1996 at a flow of 49,000 cfs and again on 25 November 1997 at a flow of 40,000 cfs. The measurements were taken in the Mississippi River main channel both upstream and downstream of Savanna Bay, in the upper and middle channel entrance to the side channel, and in the side channel of the confluence of the upper and middle channel entrances. Plates 37 and 38 describe the comparison of the prototype flow measurements to the SMS model.

Plate 39 is a plan view map of depth-averaged velocity contours output from the SMS model incorporating the 1996 prototype survey. The contours were developed from a flow of 40,000 cfs. Results indicated that higher velocities were generally found in the main navigation. However, a high area of velocity was developed between Island 266 and upper Sweeney Island. This was verified by field inspection and was also consistent with trends observed in the micro model. Plate 41 is a plan view map of depth-averaged velocity vectors developed from a flow of 124,000 cfs that further defined the expected velocity distribution of the prototype.

3. Model Output Results

Plates 39 through 49 are results of the SMS modeling effort. The effort was put forth as a compliment to the Micro Model in order to gain a better understanding of relative velocity conditions that could be expected to occur from the base test and various design alternative impacts attempted in the model tests. Due to time and budget constraints, only a few of the alternatives were numerically modeled and analyzed.

The procedure involved first importing the micro model bathymetry into the SMS modeling scheme. Various flows were tested. The resultant velocity vectors were output to gain an understanding of the relative change in velocity distribution between the base test and the various attempted design alternatives.

Base Test, *Micro Model Resultant Bathymetry, Flow of 124,000 cfs.* Plate 41 is a plan view map of the resultant depth-averaged velocity vectors using the micro model base test bathymetry at 124,000 cfs. Results indicated that generally most of the flow was contained in the main navigation channel. However, a higher concentration of flow was observed in the middle one third of the side channel in the micro model as compared to the prototype. This was undoubtedly due to a lack of applied micro model roughness near the second opening. This insight supplied by the SMS model could have been useful in further calibrating the micro model and adjusting the roughness, but the output from the SMS analysis of the base test was not available during the micro model calibration phase of the study.

Alternative 2, *Resultant Bathymetry, Flow of 124,000 cfs.* Plate 42 (0.022 n-value) and Plate 43 (0.050 n-value) are plan view maps of the resultant depth-averaged velocity vectors using the micro model bathymetry from Alternative 2 (Plate 26). Results of both tests indicated that velocities increased within the most upstream side channel opening as compared to the base test. Velocities also increased slightly against the main channel revetment at Island 266. In the middle side channel opening between Island 266 and upper Sweeney Island, velocities were reduced. In the main navigation channel, velocities were generally greater from this plan as compared to the base test.

(Alternative 4), *Resultant Bathymetry, Flow of 124,000 cfs.* Plate 44 (0.022 n-value) and Plate 45 (0.050 n-value) are plan view maps of the resultant depth-averaged velocity vectors using the micro model bathymetry from Alternative 4.

Results indicated that both tests indicated a substantial relative increase in velocity within the main navigation. Most of the general flow patterns also seemed to be concentrated against the revetment at the head of upper Sweeney Island. Backwater patterns in the upper one third of the side channel were noted using the n-value of 0.022.

Alternative 5, *Resultant Bathymetry, Flow of 124,000 cfs.* Plate 46 (n-value of 0.050) is a plan view map of the resultant depth-averaged velocity vectors using the micro model bathymetry from Alternative 5. Results indicated that the velocities were substantially increased in the main navigation channel as compared to the base test. Deflection of flow was noted at the revetment against the head of upper Sweeney Island. Velocities were slightly decreased in the upper side channel opening, remained essentially the same in the middle opening, and increased substantially in the small lower opening between Sweeney Islands. Plate 47 and Plate 48 were SMS modeling attempts to possibly alleviate the eddy formed in the main channel adjacent to upper Sweeney Island. Totally blocking the third opening and lowering bed elevations seemed to have no effect on reducing or eliminating this eddy formation.

Alternative 9, *Resultant Bathymetry, Flow of 124,000 cfs.* Plate 49 is a plan view map of the resultant depth-averaged velocity vectors using the micro model bathymetry from Alternative 9. Results indicated that velocities generally decreased in the side channel and increased in the main navigation channel.

RESULTS AND CONCLUSIONS

1. Summary of Model Tests

- Alternatives 2,5,9,10, and 11 produced the greatest improvements to the general condition of the navigation channel, creating both additional width and depth as compared to the base test conditions.

- Alternative 5 would effectively reduce the usable channel at Mile 539.6. This alternative would probably not be accepted by industry because of safety concerns. Other alternatives either did not generate enough of an effect on the navigation channel, or else generated too much of an effect thereby changing the location of the downstream thalweg. Adding a third closure structure at the most downstream opening of Sweeney Islands eliminated any trends for delta deposition or additional deposition in the side channel.

- All closure structure alternatives that were tested in this study had a tendency to change conditions downstream of the dredging area at Mississippi Palisades State Park (left descending bank). Depths developed in this area were directly related to the change of flow conditions within the side channel provided by the closure structures. The most attractive alternative to address this condition was Alternative 11.

- Lowering the closure structures in Alternative 11 reduced localized scour at the island revetments and openings. The additional flow allowed through the side channel as compared to the higher closure alternatives created relatively deeper depths downstream near Mississippi Palisades State Park.

- The tests conducted in this study indicated that the wing dam alternatives had a tendency to deflect flow directly at the head of upper Sweeney Island. The micro model flow visualization and SMS modeling results verified this trend. The closure structure alternatives seemed to distribute flow more uniformly through the navigation channel.

- It is recommended that if the District pursues closure structure implementation in the river, a phased construction plan would be advantageous. Phase 1 could call for construction of the three closure structures at a height equal to or less than 5 feet below flat pool. Prototype surveys could then monitor changes after one or two open-river events. If more closure effect is desired, then phase 2 could call for raising the closures to an additional height.

- Measured velocities between 5 to 10 feet per second are not uncommon in the Upper Mississippi River during open-river, high flow events. It is recommended that to ensure structural integrity of the closure structures under these conditions, Grade A or Quarry-Run stone should be used for dike construction with a maximum top size of 5000 pounds.

2. Interpretation of Model Test Results

In the interpretation and evaluation of the results of the tests conducted, it should be remembered that the results of these model tests were qualitative in nature. Any hydraulic model, whether physical or numerical, is subject to biases introduced as a result of the inherent complexities that exist in the prototype. Anomalies in actual hydrographic events, such as prolonged periods of high or low flows, are not reflected in these results, nor are any complex physical

phenomena, such as the existence of underlying rock formations or other non-erodible variables.

This study effort illustrated that the micro model, flow visualization, and the SMS model could be used complimentary applied river engineering tools for channel design evaluation. Calibration of the micro model could have been further improved by use of the SMS model, but timing of the SMS modeling output was such that this was not possible during this study.

Finally, it should be noted that the innovative ideas set forth in this study were developed as a result of a cooperative effort between all of the aforementioned agencies. "Hands on" experimentation at the Applied River Engineering Center (Plate 28) enabled both biologists and engineers to formulate design alternatives and experiments in the micro model.

BIBLIOGRAPHY

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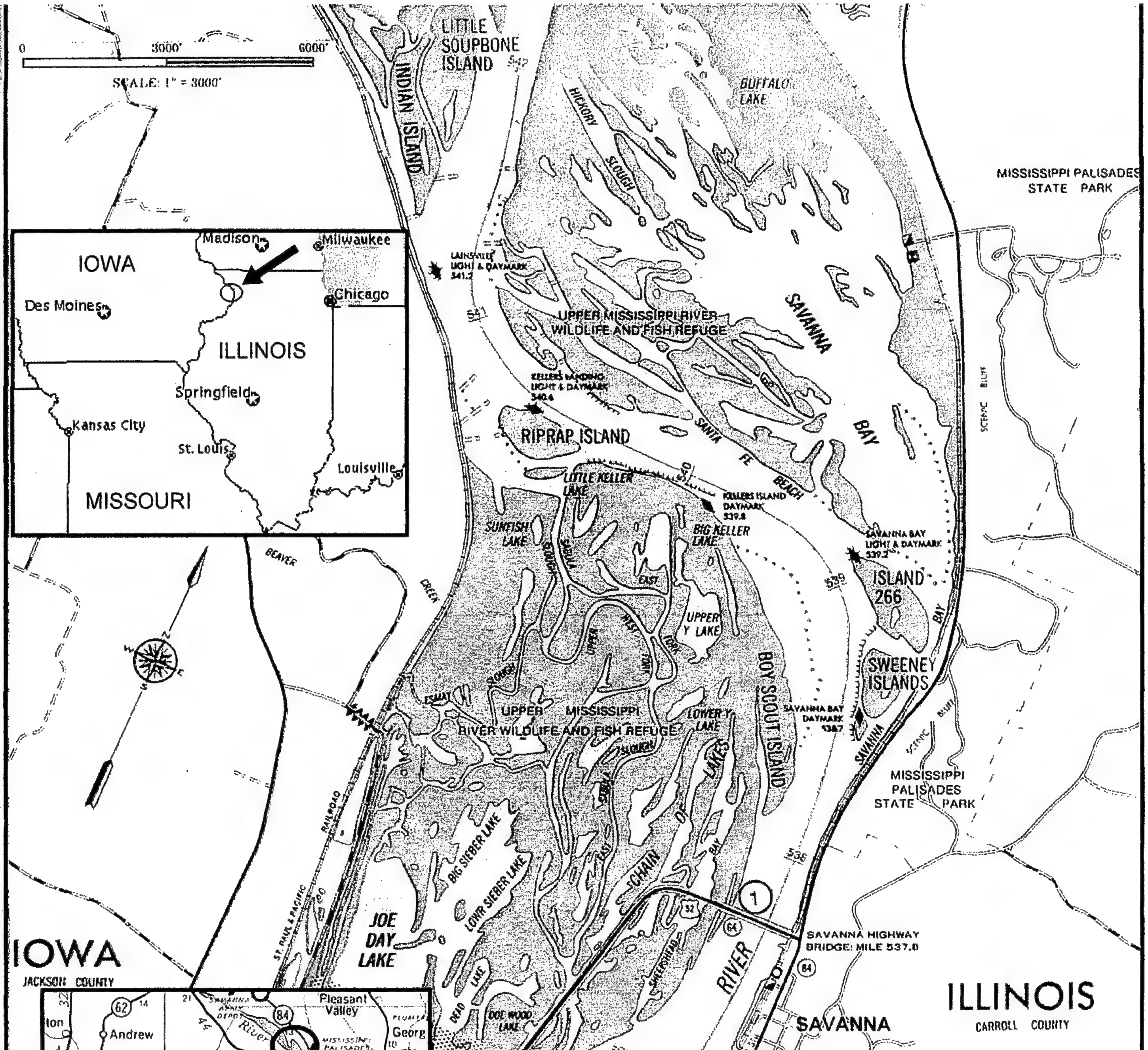
2. Leopold, Luna B., A View of the River, Harvard University Press, Cambridge Massachusetts, London, England, 1995.

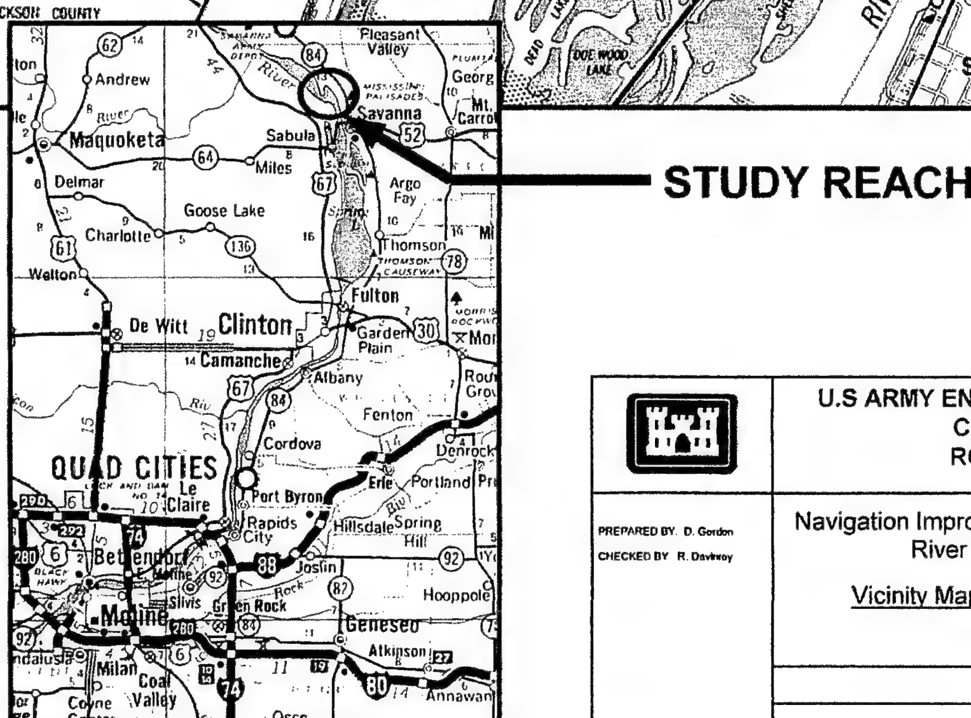
3. Davinroy, Robert D., Micro Scale Sediment Modeling (Micro Modeling) of Inland Waterways, Proceedings of the Sixth Federal Interagency Sedimentation Conference, Las Vegas, Nevada, 1996.

4. Engineering Computer Graphics Laboratory, Brigham Young University, SMS Surface Water Modeling System, Reference Manual, March 1997

APPENDIX

Plates 1 through 49 will follow.





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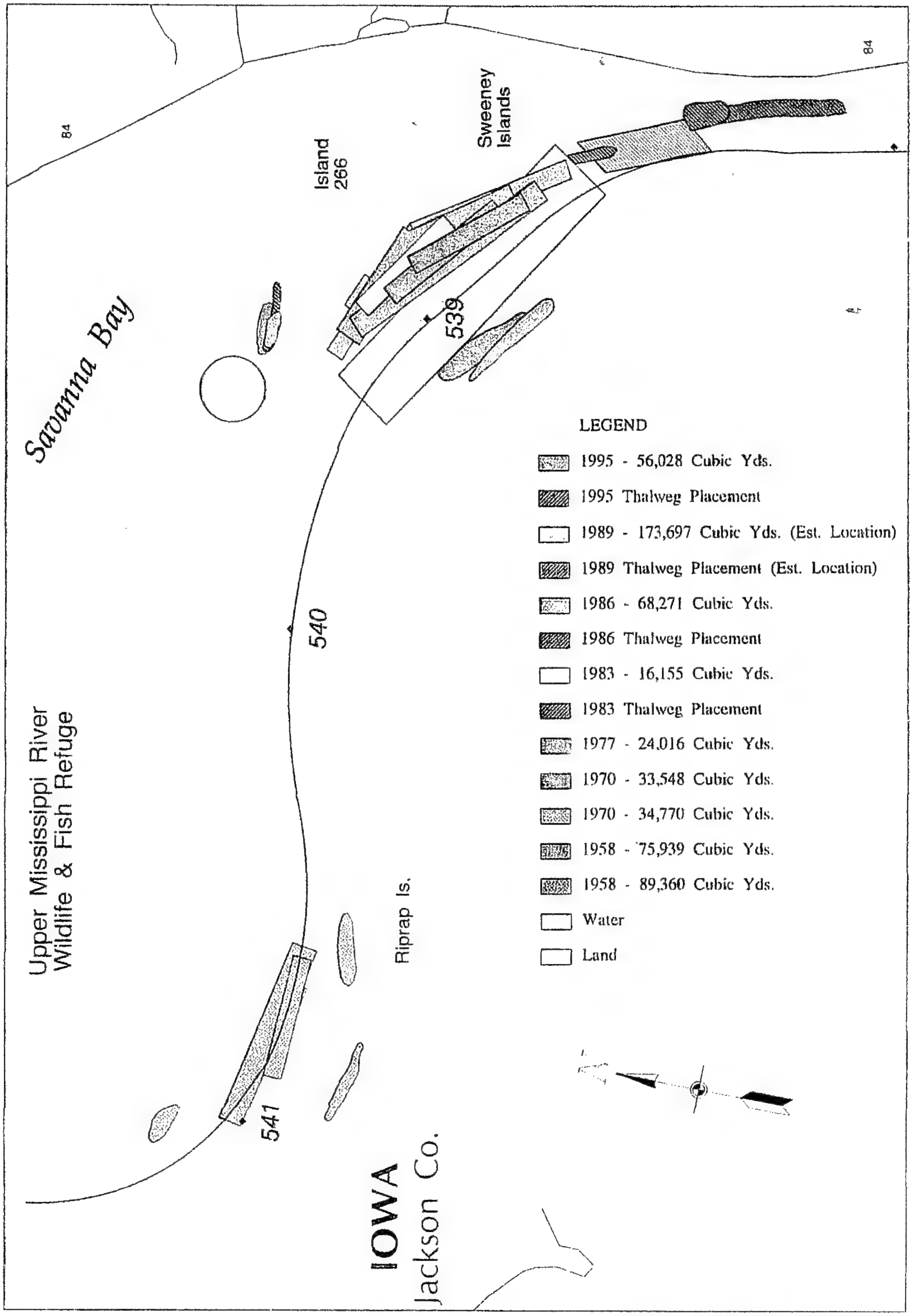
CHECKED BY: R. Davinroy

Navigation Improvement Study of the Upper Mississippi River Near Savanna Bay, Pool 13

Vicinity Map of the Micro Model Study Reach

PLATE NO
1



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CHECKED BY R. Davinrey

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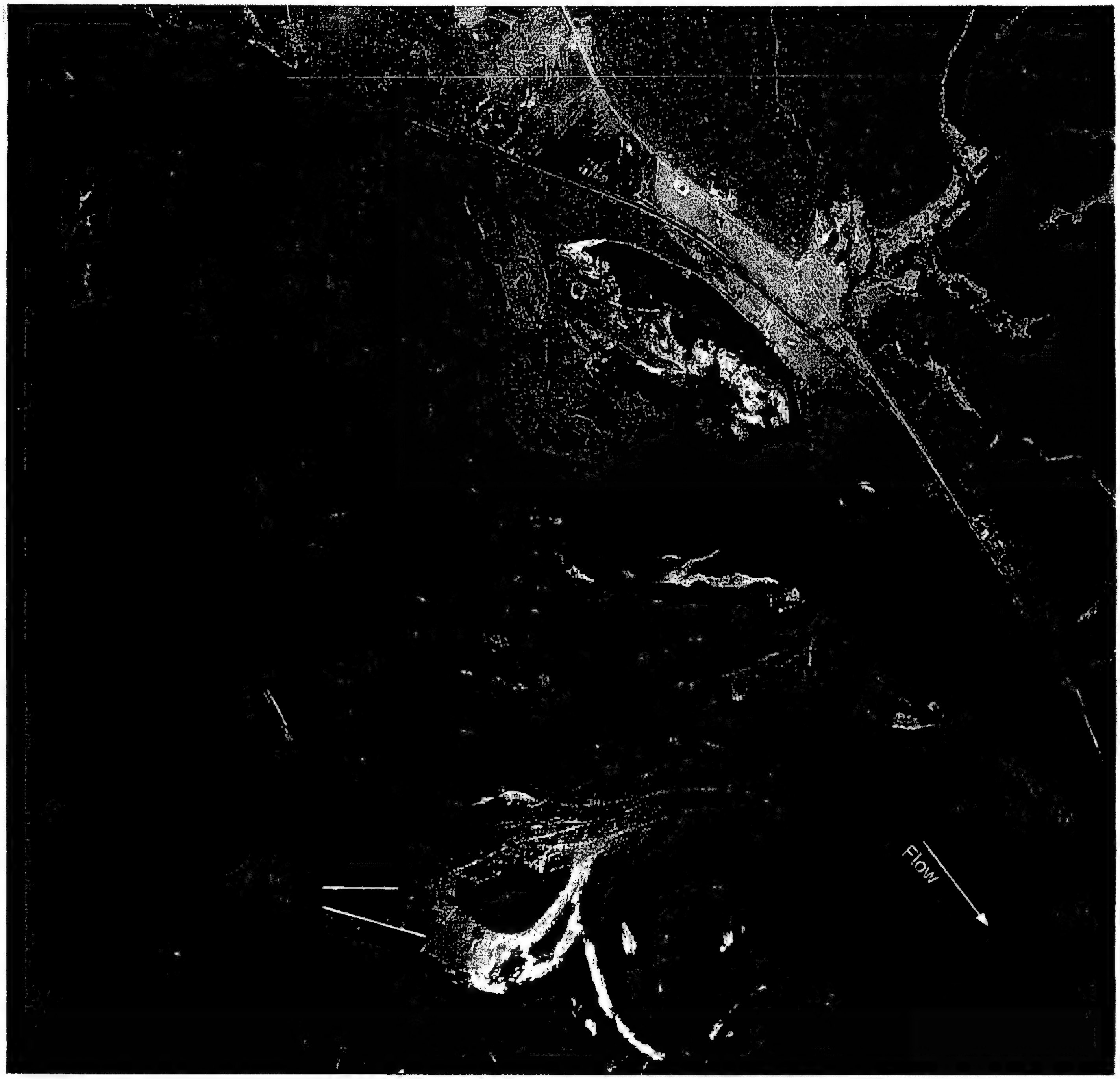
Dredge Cuts & Dredged Material Placement Sites

PLATE NO
2



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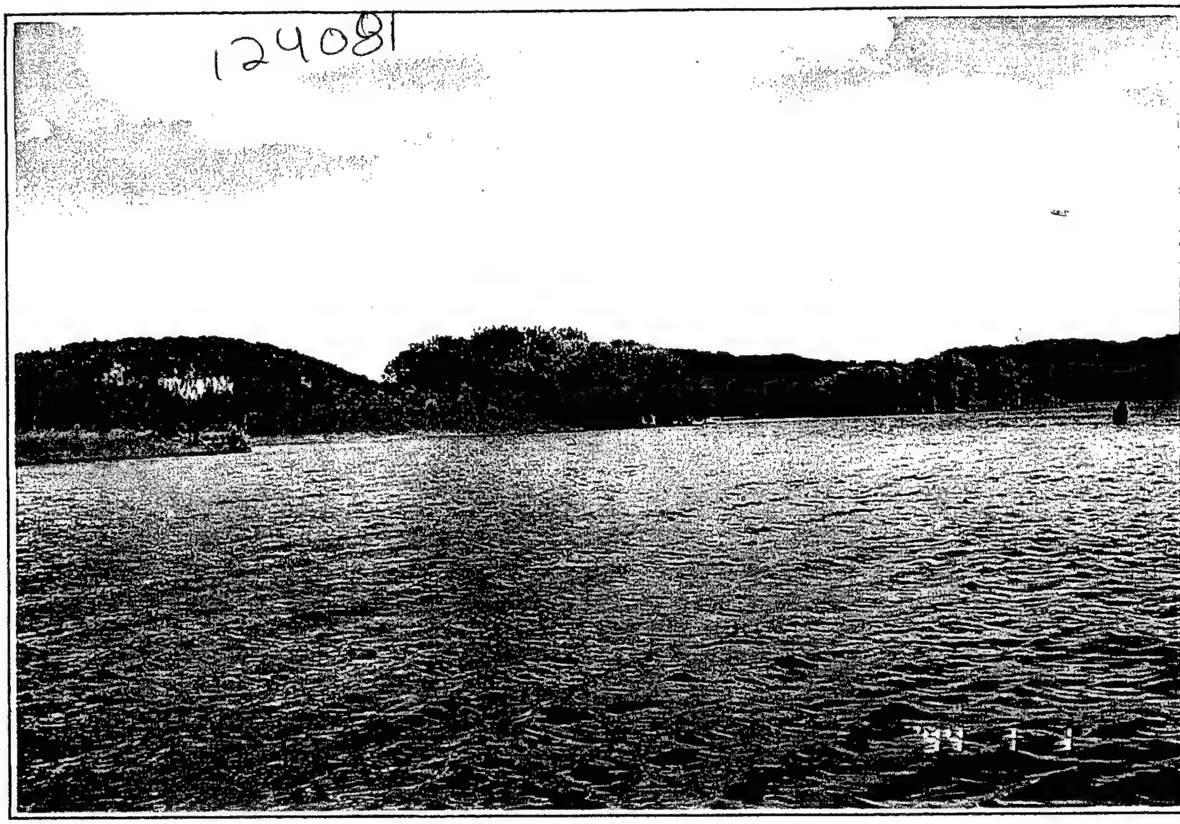
Aerial Infrared Photo of Study Reach

PLATE NO. 3

124080



Side Channel Openings Between Santa Fe Beach, Island 266, and Sweeney Islands, Looking Downstream Toward the Illinois Bank

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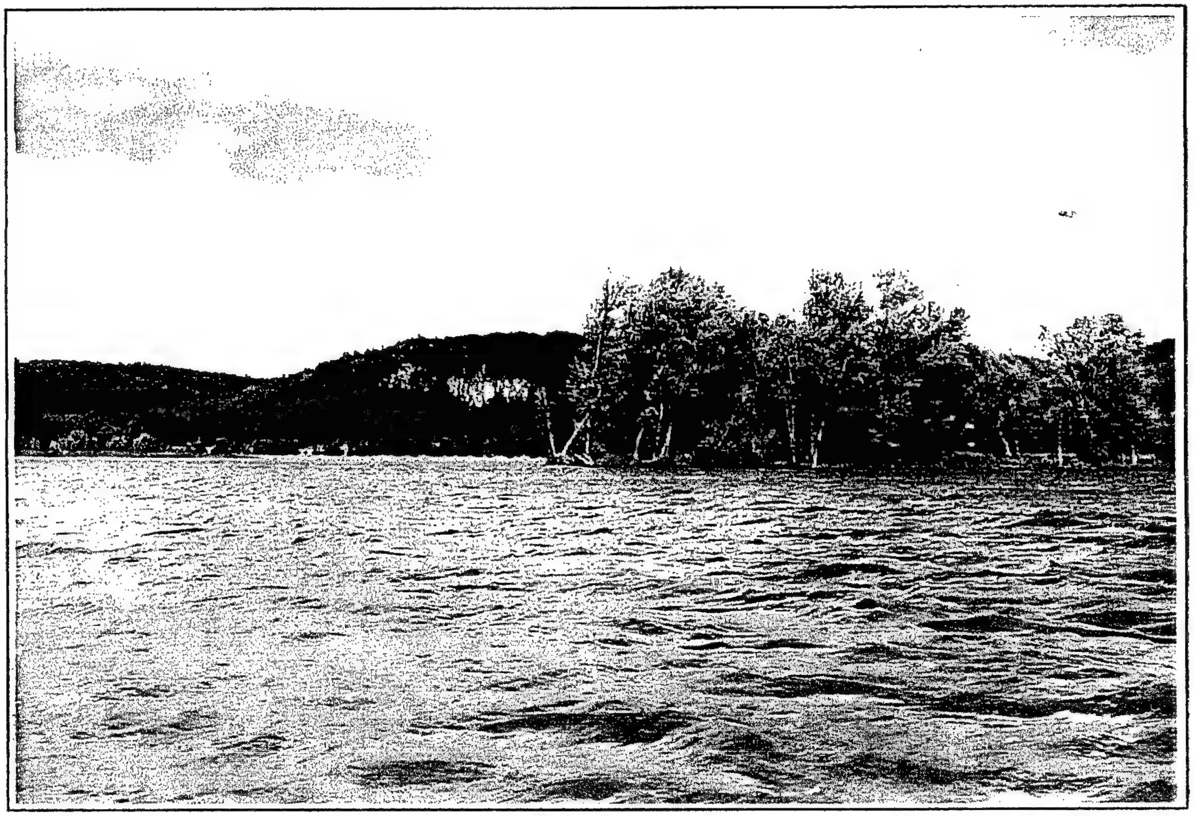
PREPARED BY R Davinroy CHECKED BY D Gordon	Navigation Improvement Study of the Upper Mississippi River Near Savanna Bay, Pool 13 Field Photos of June 16, 1997
	PLATE NO. 4



Looking Upstream at the Side Channel Opening, Island 266 is to the Right

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PREPARED BY: N. Dimitrov
CHECKED BY: D. Gordon

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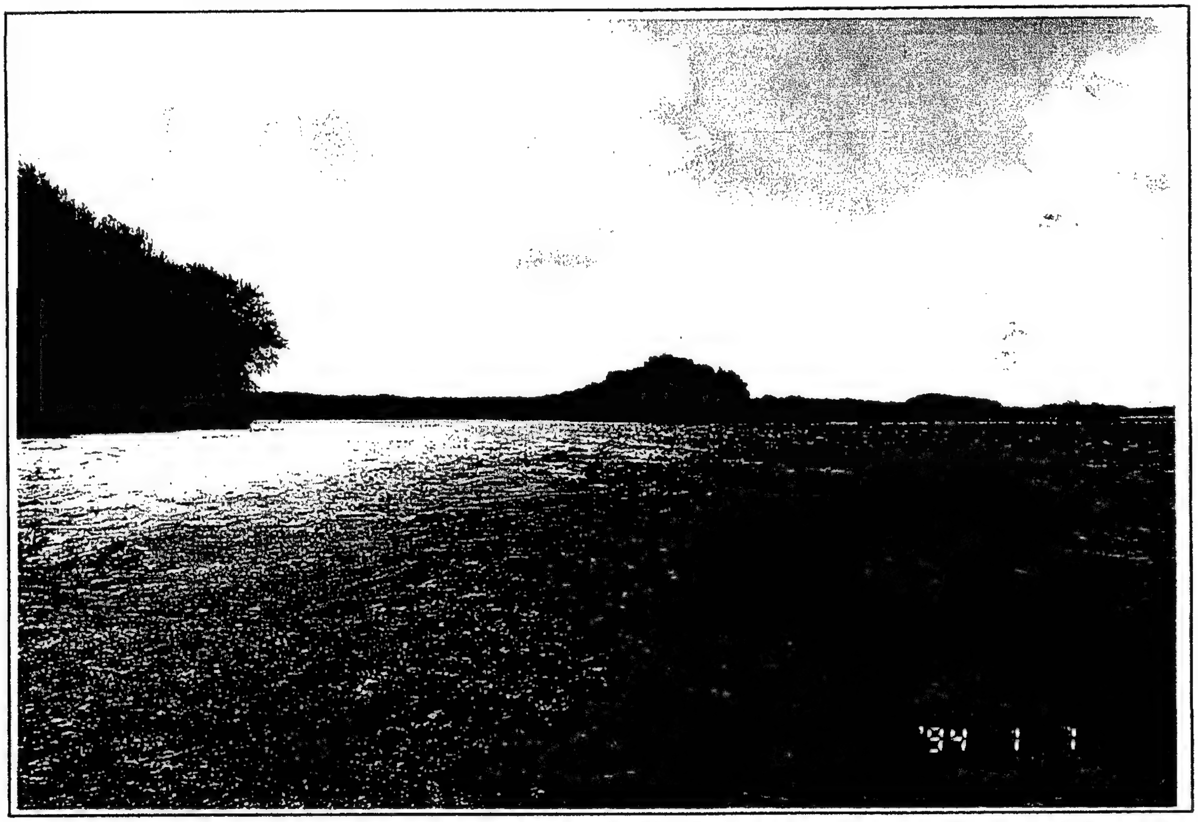
Field Photos of June 16, 1997

PLATE NO. 5



Looking Upstream Within the Side Channel Opening Between Island 266 (Left) and Santa Fe Beach, Savanna Bay is to the Far Right

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PREPARED BY R Davinroy
CHECKED BY D Gordon

Navigation Improvement Study of the Upper Mississippi River Near Savanna Bay, Pool 13

Field Photos of June 16, 1997

PLATE NO

6

Within the Side Channel, Looking Directly Downstream Toward the Savanna Highway Bridge

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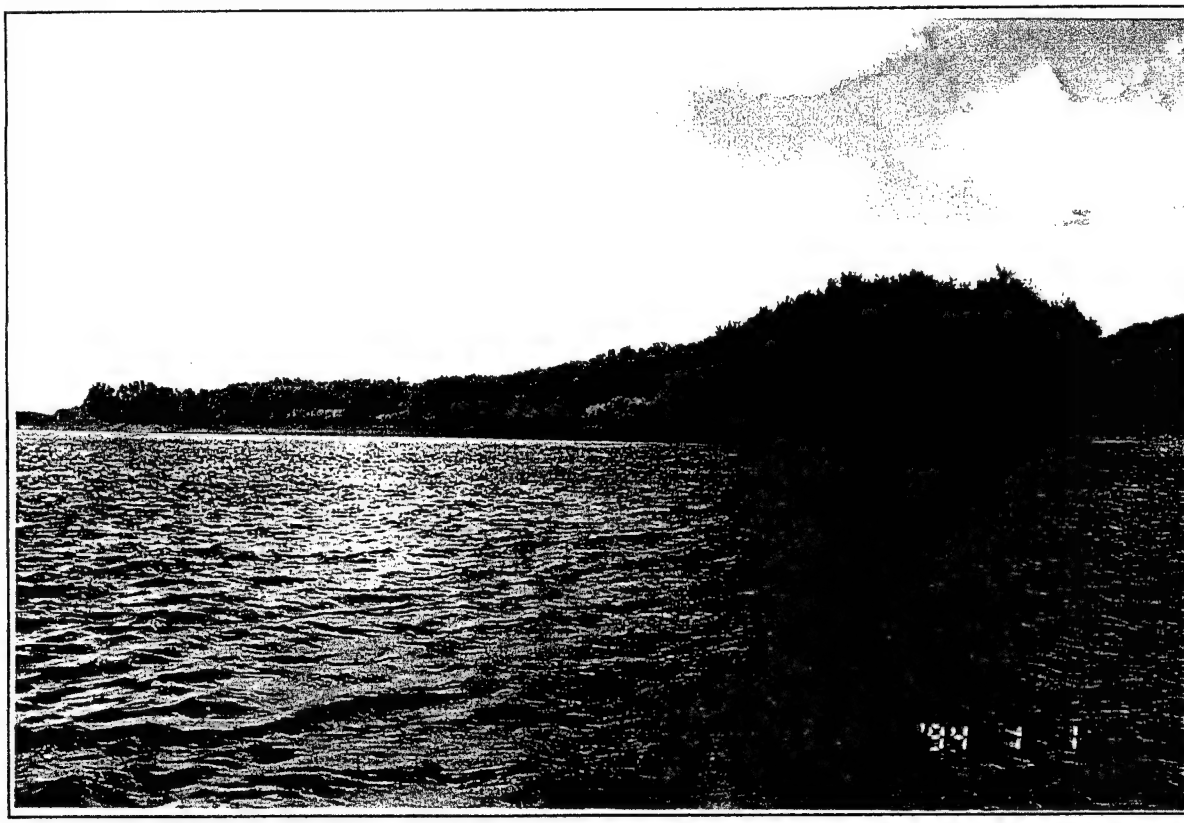
Field Photos of June 16, 1997

PLATE NO
7



In the Main Channel, Looking Upstream Toward Island 266

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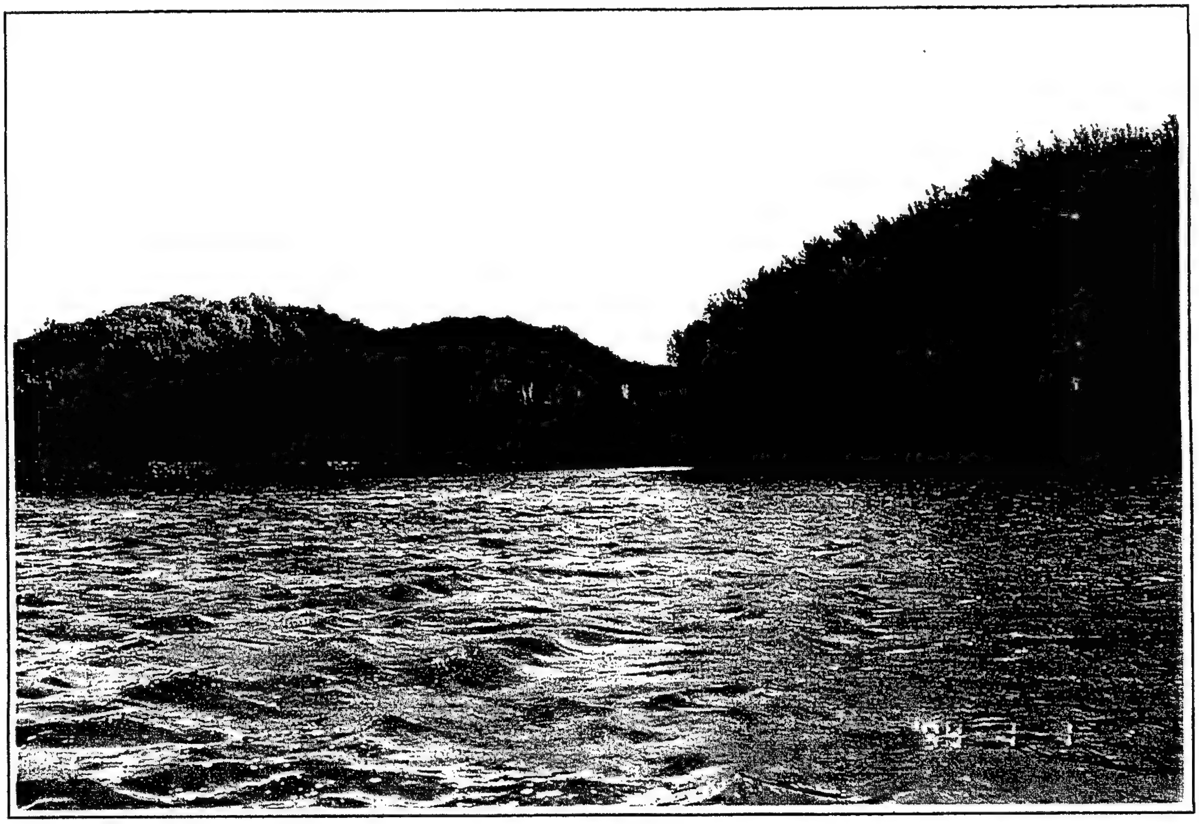
PREPARED BY R Davinroy CHECKED BY D Gordon	Navigation Improvement Study of the Upper Mississippi River Near Savanna Bay, Pool 13 Field Photos of June 16, 1997
	PLATE NO. 8



Looking Downstream Within the Side Channel,
Illinois Bankline on the Left and Island 266 on the Right

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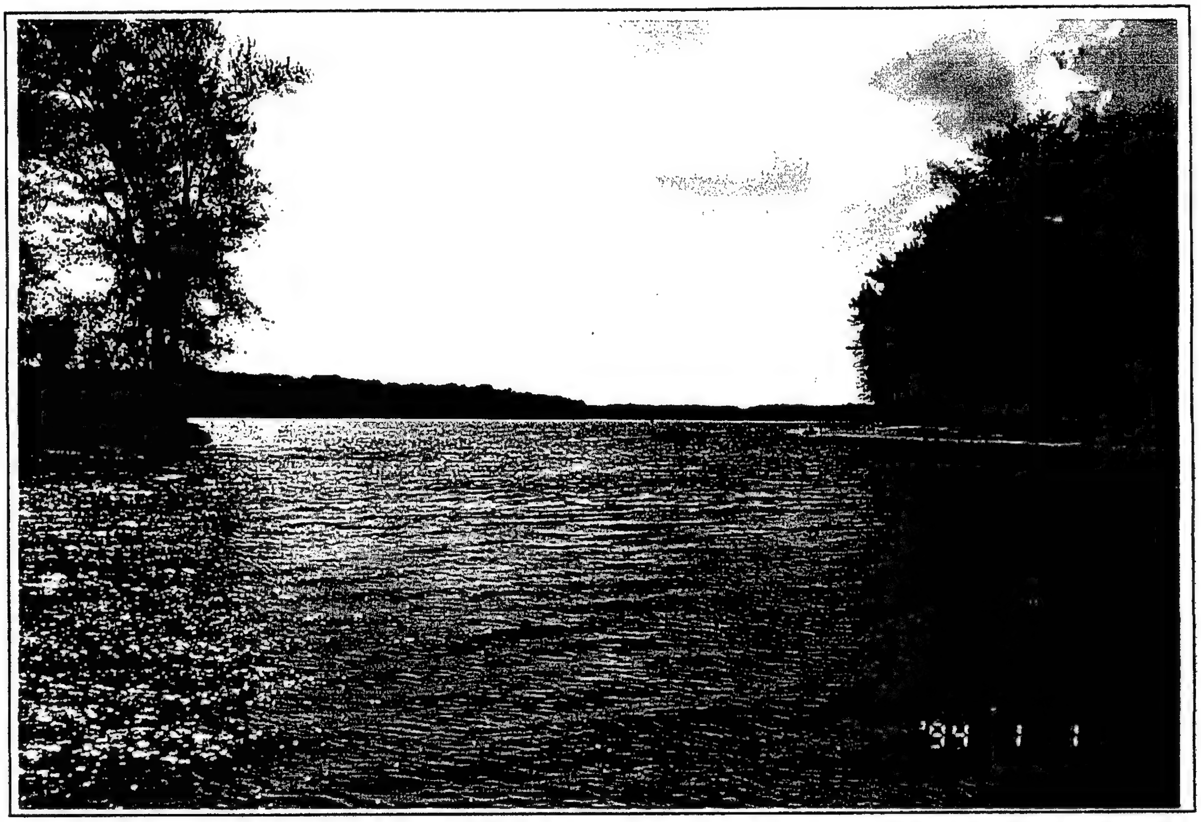
Navigation Improvement Study of the Upper Mississippi River Near Savanna Bay, Pool 13

Field Photos of June 16, 1997

PLATE NO 9



Within the Side Channel, Looking Upstream Through the Opening Between Sweeney Islands

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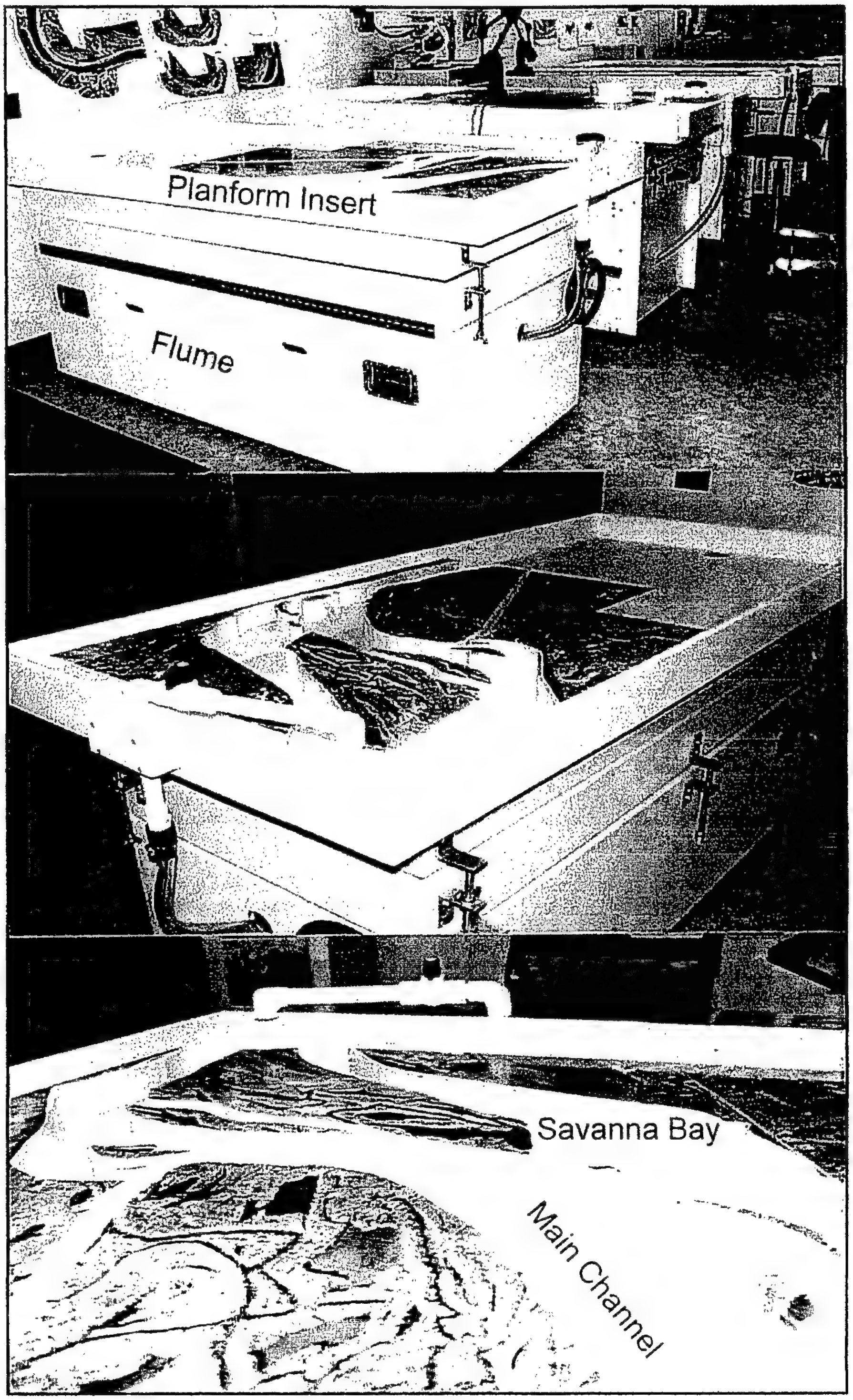
PREPARED BY R Davinroy CHECKED BY D Gordon	Navigation Improvement Study of the Upper Mississippi River Near Savanna Bay, Pool 13 Field Photos of June 16, 1997
	PLATE NO 10



U.S. Patent
5653592

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PREPARED BY: R. Davinroy CHECKED BY: D. Gordon	Navigation Improvement Study of the Upper Mississippi River Near Savanna Bay, Pool 13 <u>Savanna Bay Micro Model</u>
	PLATE NO **11**

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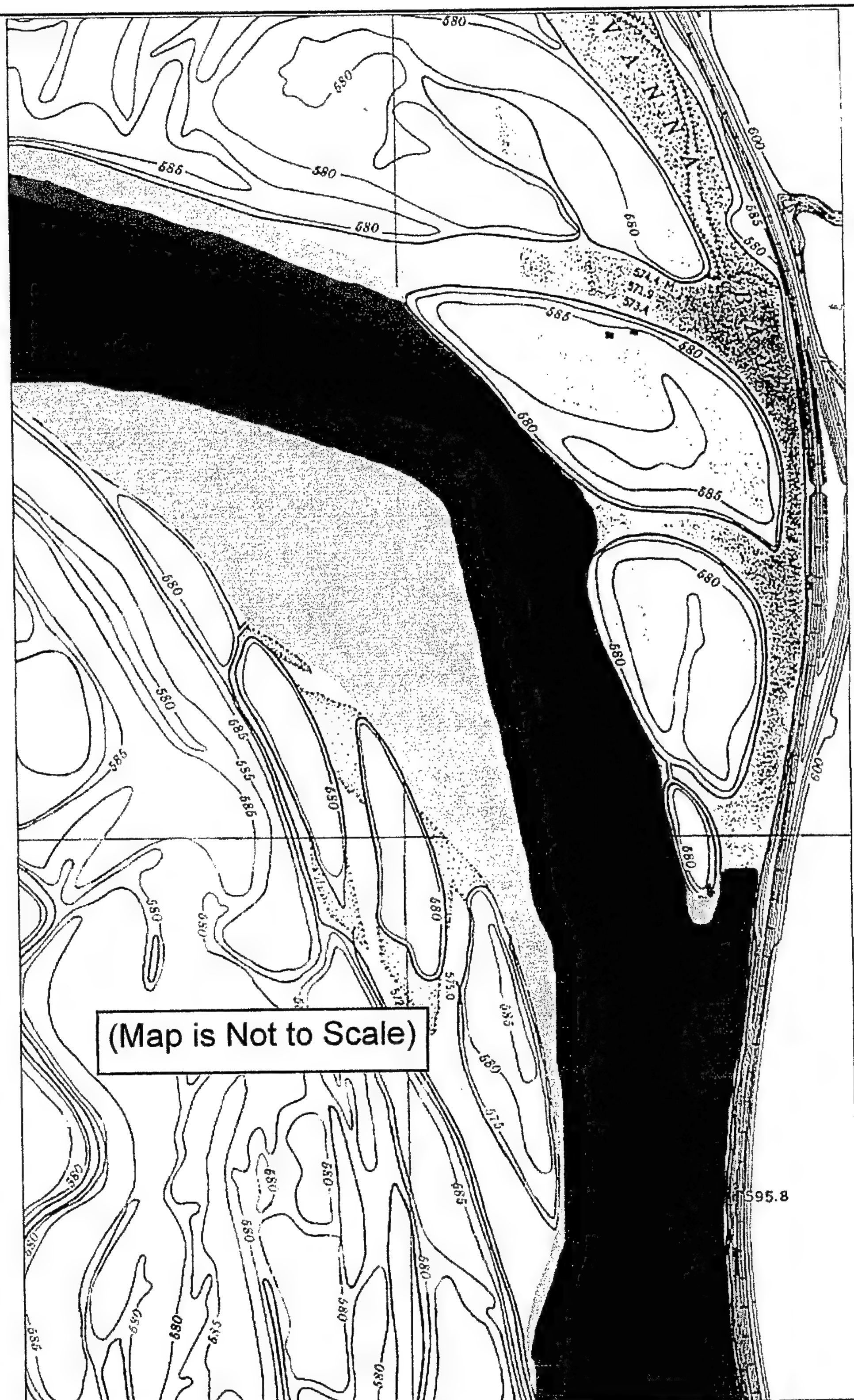
PREPARED BY: D. Gordon
CHECKED BY: R. Davinay

Navigation Improvement Study of the Upper Mississippi River Near Savanna Bay, Pool 13

1880 Topographic and Hydrographic Survey

PLATE NO.
12



Elevations Referenced to LWRP

0 FT
-10 FT
-20 FT
-30 FT
-40 FT

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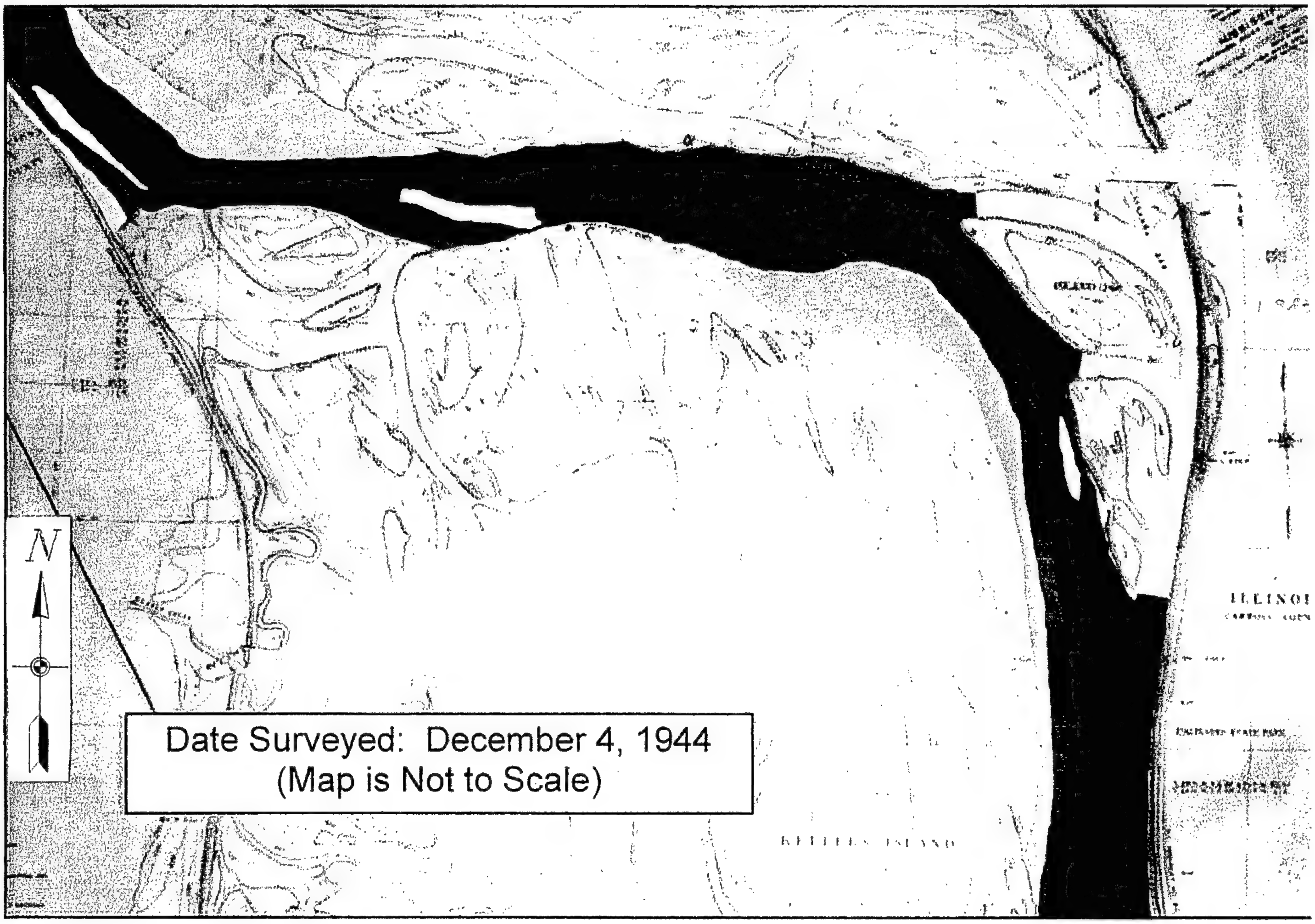
1927 Prototype Survey

PLATE NO. **13**



Elevations Referenced
Above or Below Flat Pool

	0 FT
	-10 FT
	-20 FT
	-30 FT
	-40 FT

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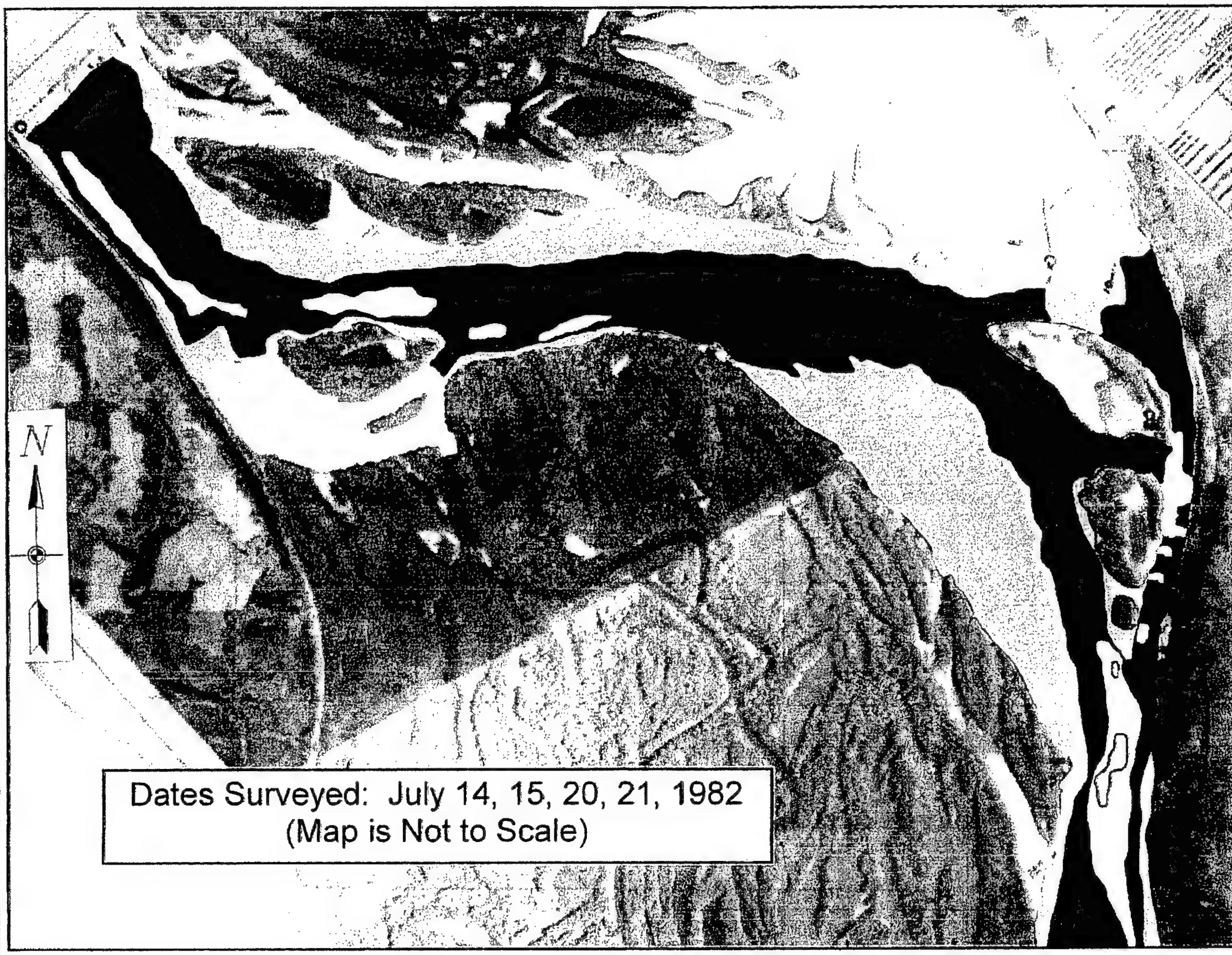
1944 Prototype Survey

PLATE NO
14



Dates Surveyed: July 14, 15, 20, 21, 1982
(Map is Not to Scale)

Elevations Referenced
Above or Below Flat Pool

	0 FT
	-10 FT
	-20 FT
	-30 FT
	-40 FT

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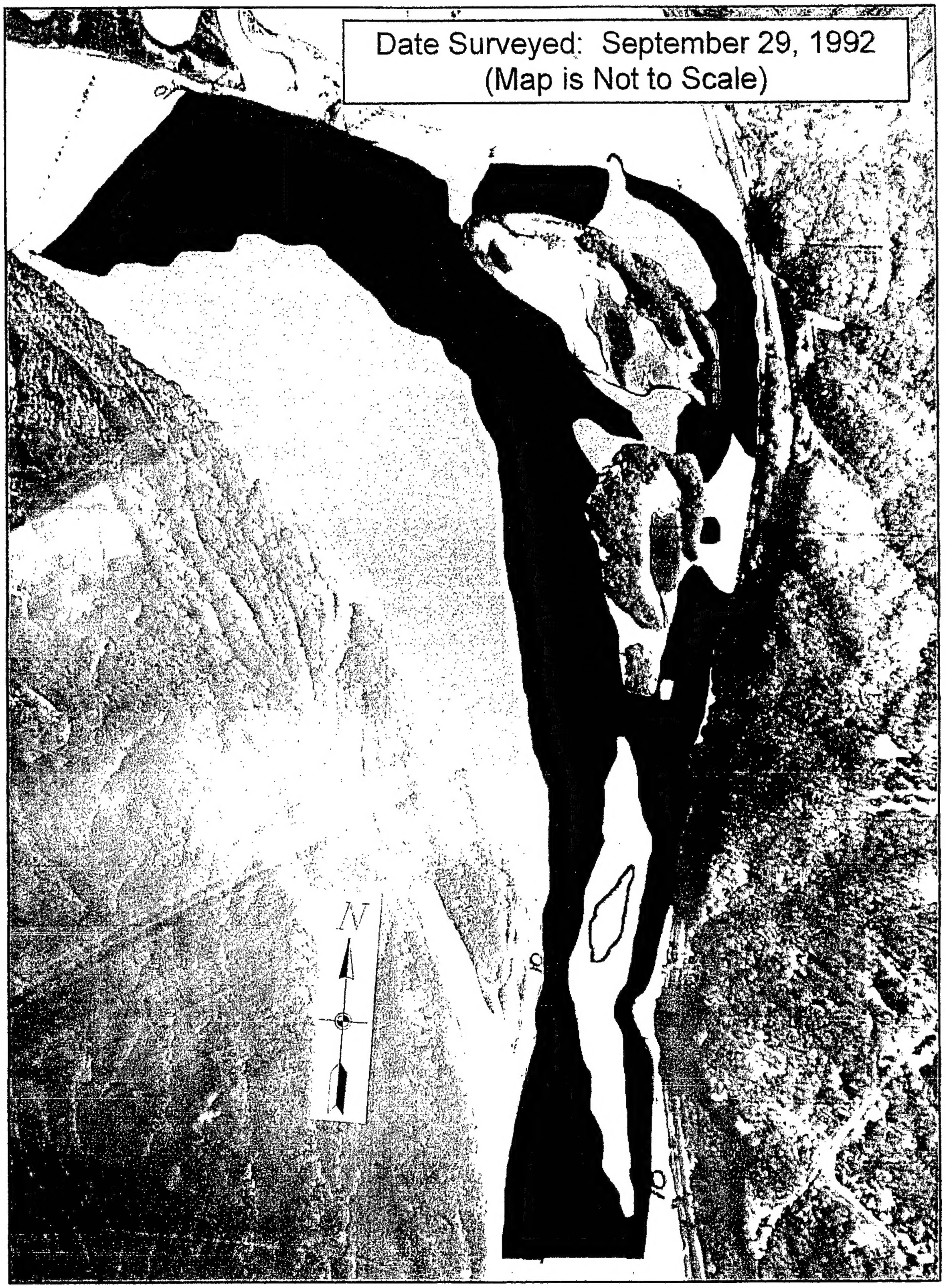
1982 Prototype Survey

PLATE NO
15



Elevations Referenced
Above or Below Flat Pool

0 FT
-10 FT
-20 FT
-30 FT
-40 FT

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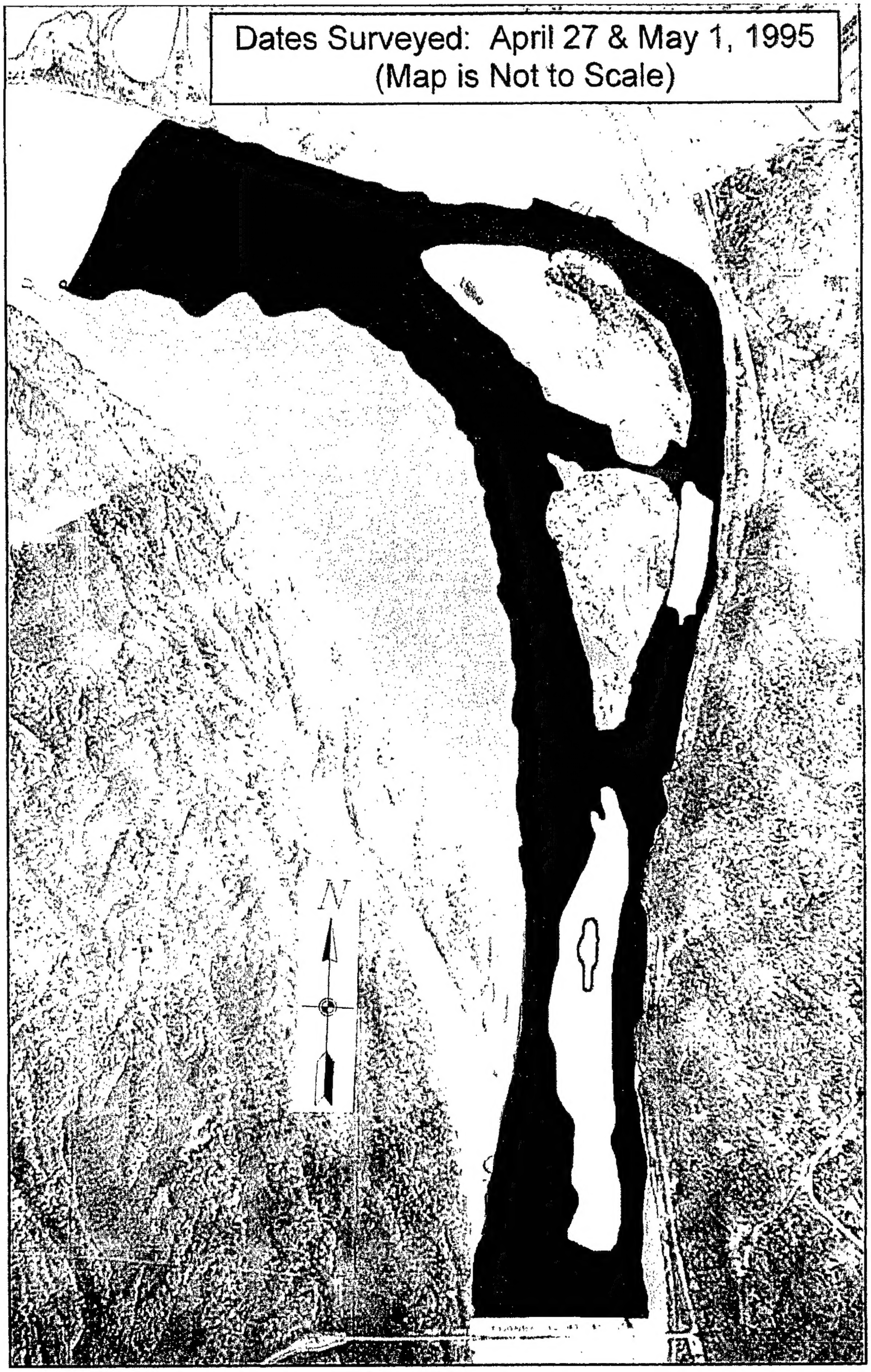
Navigation Improvement Study of the Upper Mississippi River Near Savanna Bay, Pool 13

1992 Prototype Survey

PLATE NO
16



Elevations Referenced
Above or Below Flat Pool

0 FT
-10 FT
-20 FT
-30 FT
-40 FT

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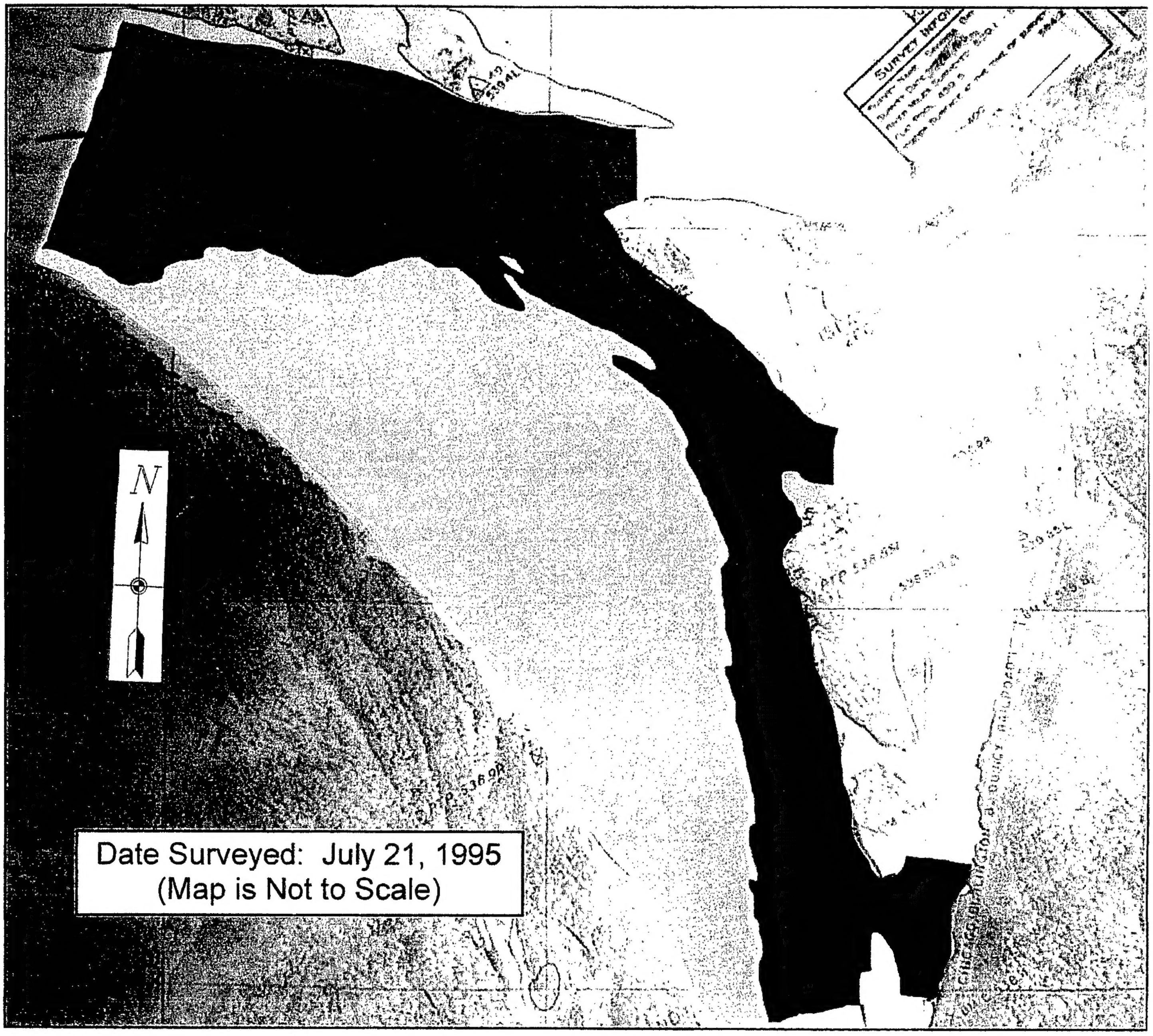
1995 Prototype Survey

PLATE NO 17



Elevations Referenced
Above or Below Flat Pool

0 FT
-10 FT
-20 FT
-30 FT
-40 FT

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PREPARED BY: D. Gordon
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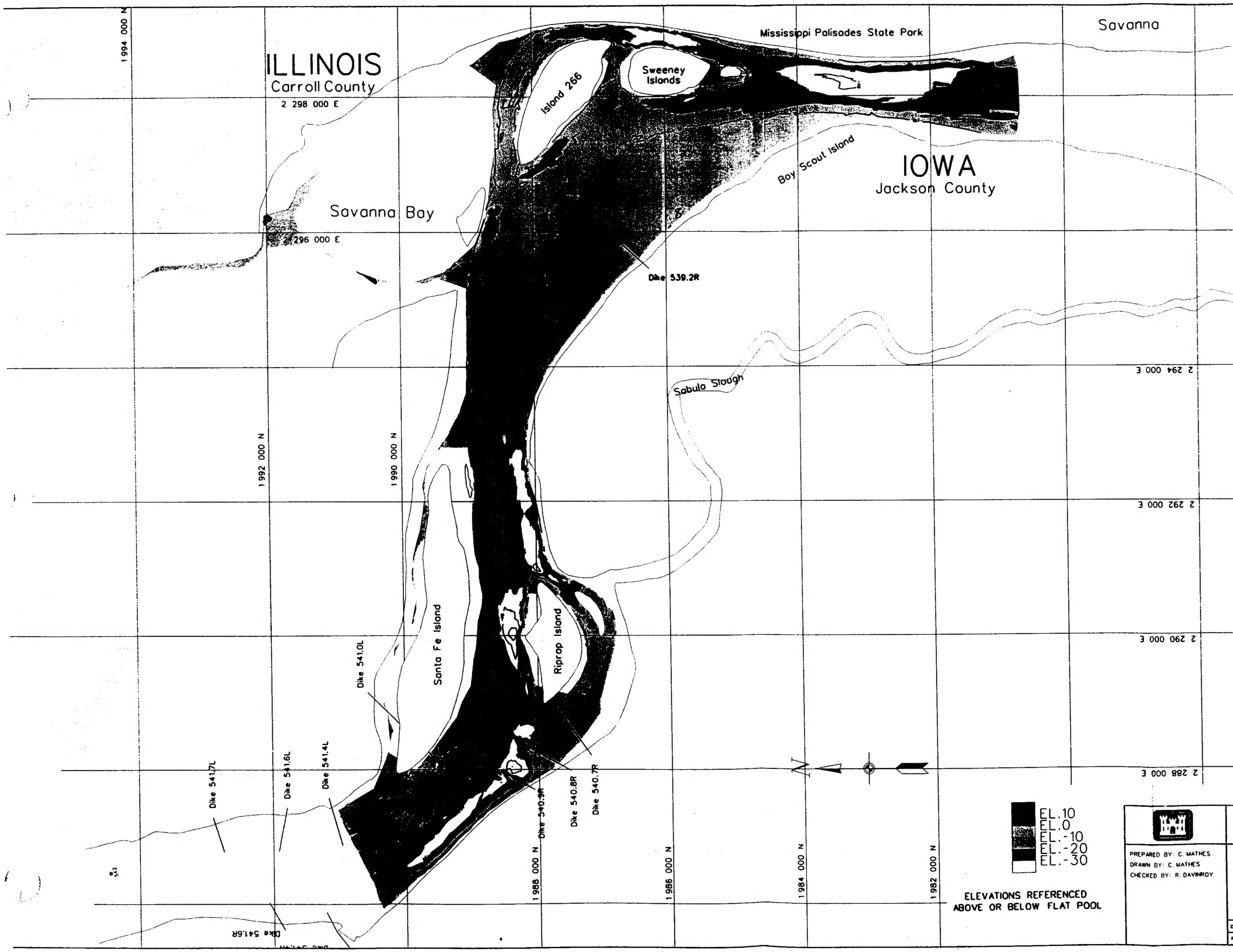
Navigation Improvement Study of the Upper Mississippi River Near Savanna Bay, Pool 13

1995 Prototype Survey

PLATE NO. **18**



PREPARED BY: C. MATHES
DRAWN BY: C. MATHES
CHECKED BY: R. DAVINROY

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SAVANNA BAY MICRO MODEL STUDY
MISSISSIPPI RIVER MILES 540-538
1996 Prototype Survey

1400 700 0 1400 FT

DESIGN FILE: SAVANNA BAY
PLOT SCALE: 1" = 1400'
PLOT DATE: FEB 98
PLATE NO. 19